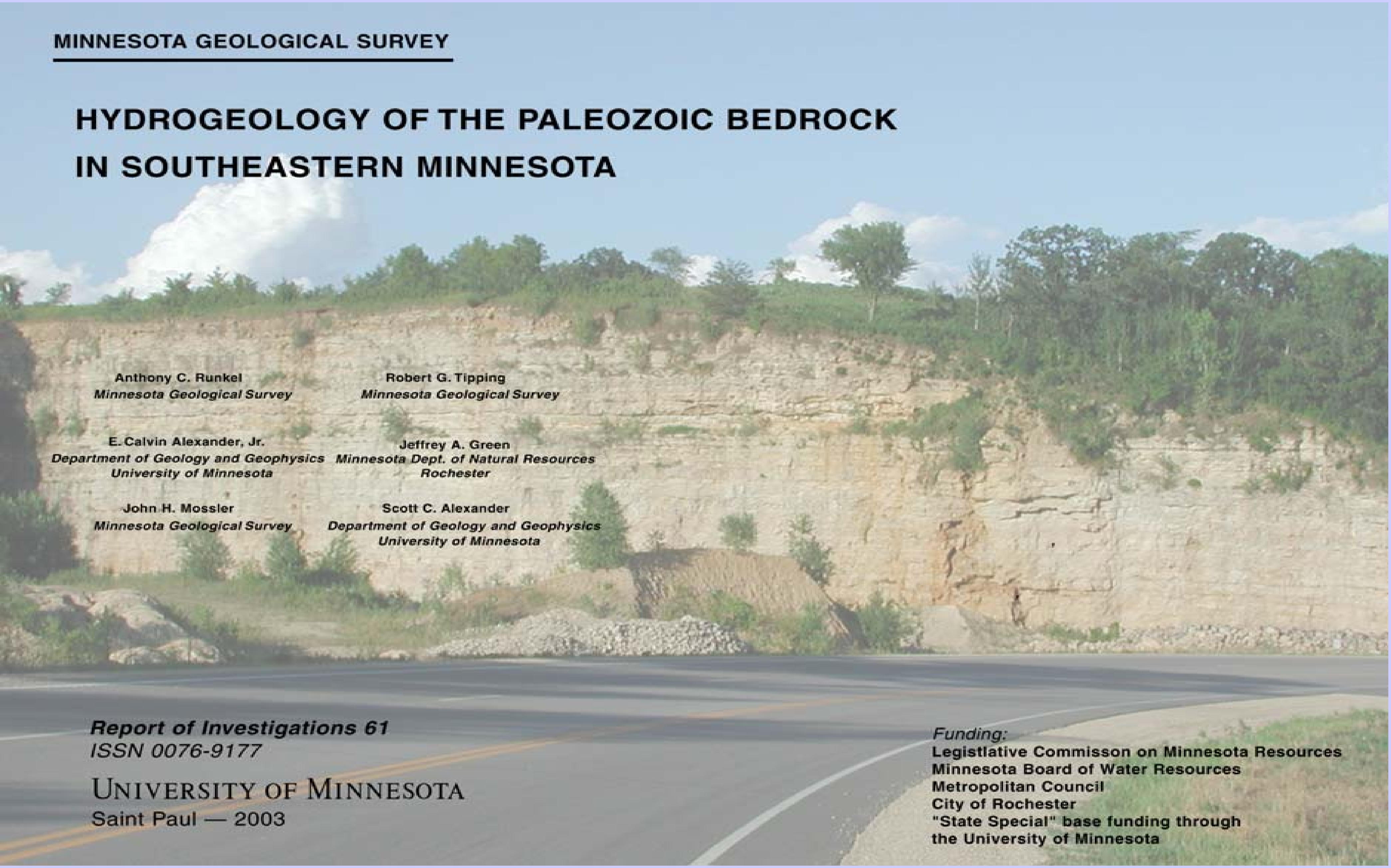
A HYDROSTRATIGRAPHICALLY BASED HYDROGEOLOGIC FRAMEWORK FOR SEDIMENTARY BEDROCK; PROVIDING IMPROVED CONTEXT FOR SITE-SPECIFIC INVESTIGATIONS



MINNESOTA GEOLOGICAL SURVEY

HYDROGEOLOGY OF THE PALEOZOIC BEDROCK IN SOUTHEASTERN MINNESOTA

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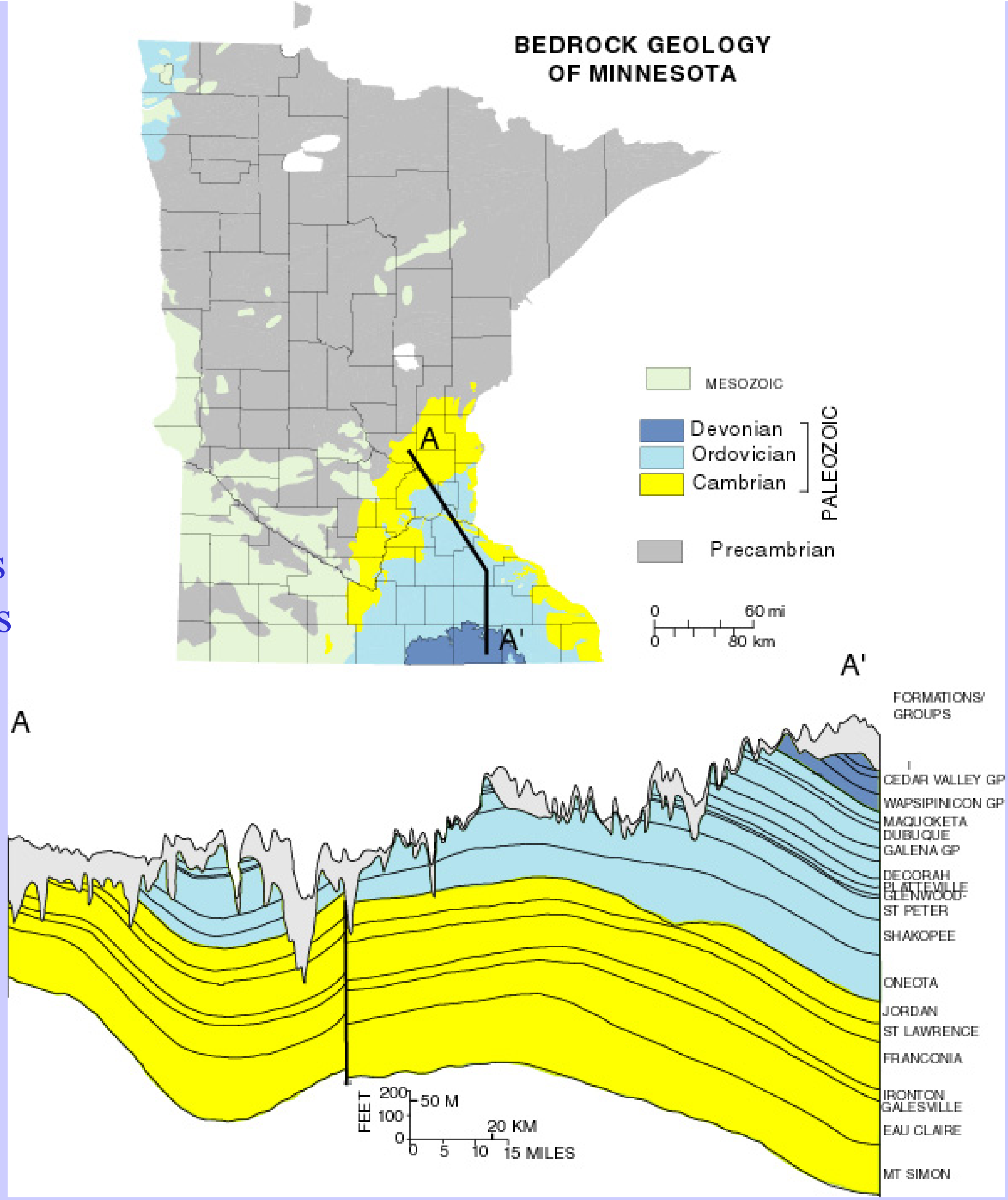
Paleozoic Bedrock
Layers of Sandstone, Shale, and Carbonate (limestone and dolostone)
About 500 to 350 Million Years Old
Most Widely Used Aquifers in Minnesota

Pz. bedrock largely beneath thin (<100 ft) cover of "glacial drift"

Gently folded and cut by high angle faults

Thin, widespread layers piled to a total thickness of about 2000 ft.



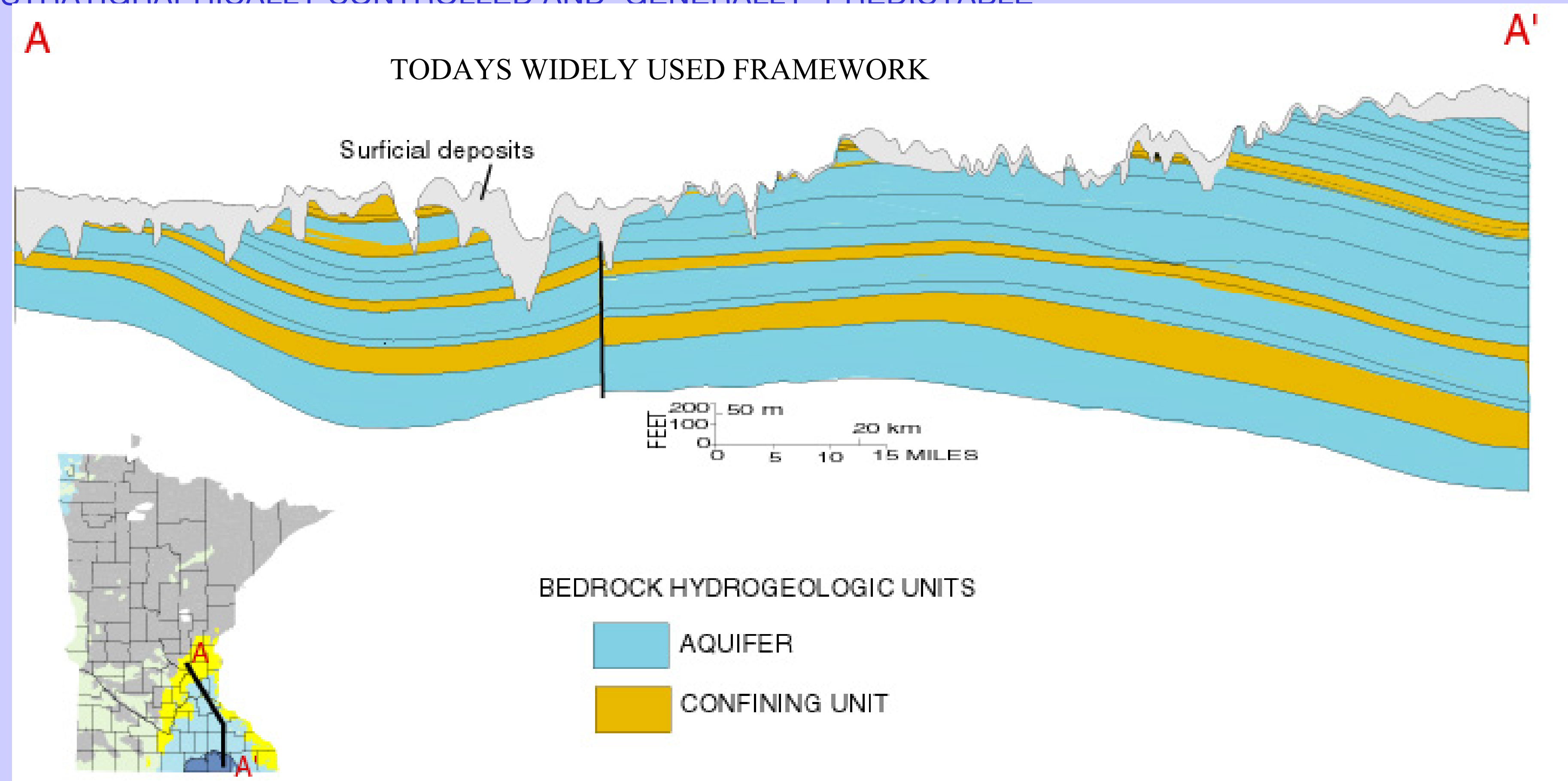
EXISTING FRAMEWORK FAILS AS A GUIDE FOR SITE-SPECIFIC INVESTIGATIONS
A NEW FRAMEWORK BASED ON SITE SPECIFIC INFORMATION IS MARKEDLY MORE ACCURATE AT ALL SCALES

NEW FRAMEWORK INDICATES THAT

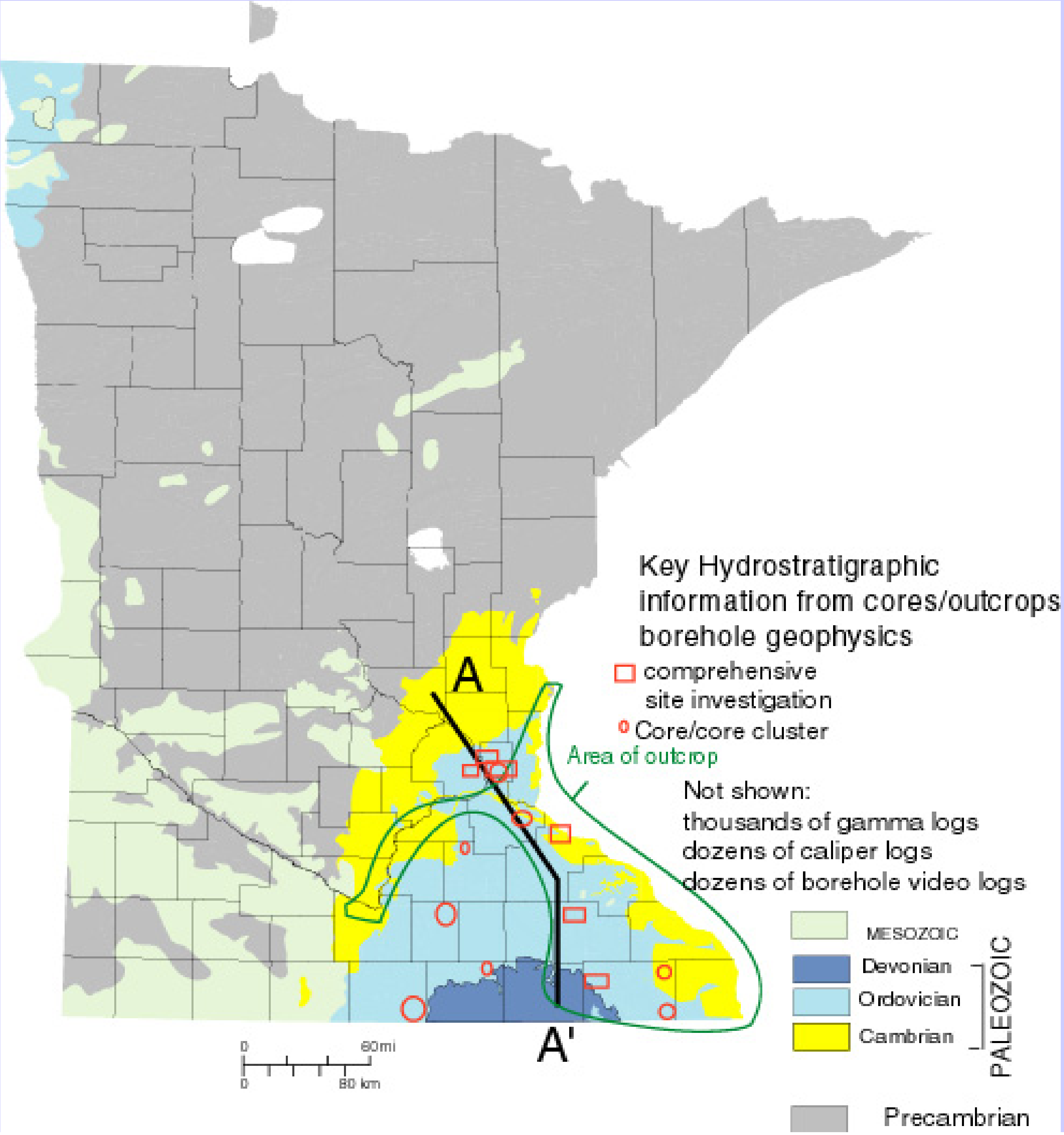
-ALL BEDROCK HAS SECONDARY PORES, AND SECONDARY PORES DOMINATE HYDRAULICS EVEN IN MOST POROUS, FRIABLE SANDSTONES

-HYDRALICALLY IMPORTANT SECONDARY PORES ARE “GENERALLY” PREDICTABLE BECAUSE THEY ARE STRATIGRAPHICALLY CONTROLLED

-SIMILARLY, IMPORTANT BARRIERS SEPARATING FRACTURED INTERVALS ARE LIKEWISE STRATIGRAPHICALLY CONTROLLED AND “GENERALLY” PREDICTABLE

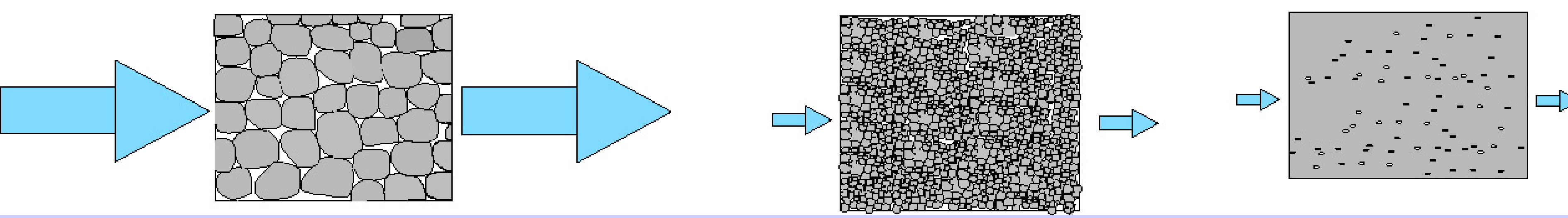


STEP ONE: BUILDING A HYDROSTRATIGRAPHIC FRAMEWORK: DEFINING AND MAPPING MATRIX AND SECONDARY PORES

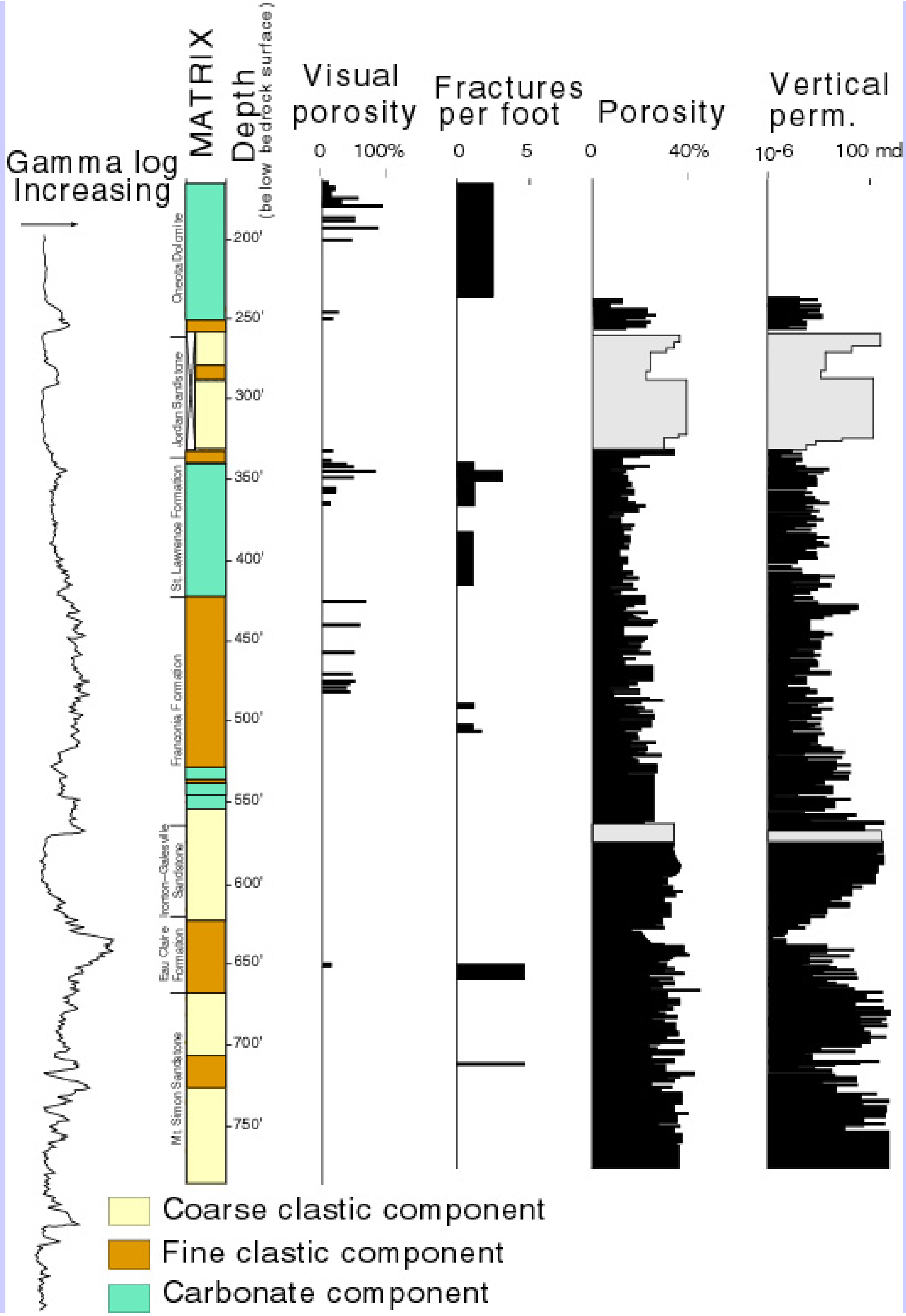


Principle Matrix Components

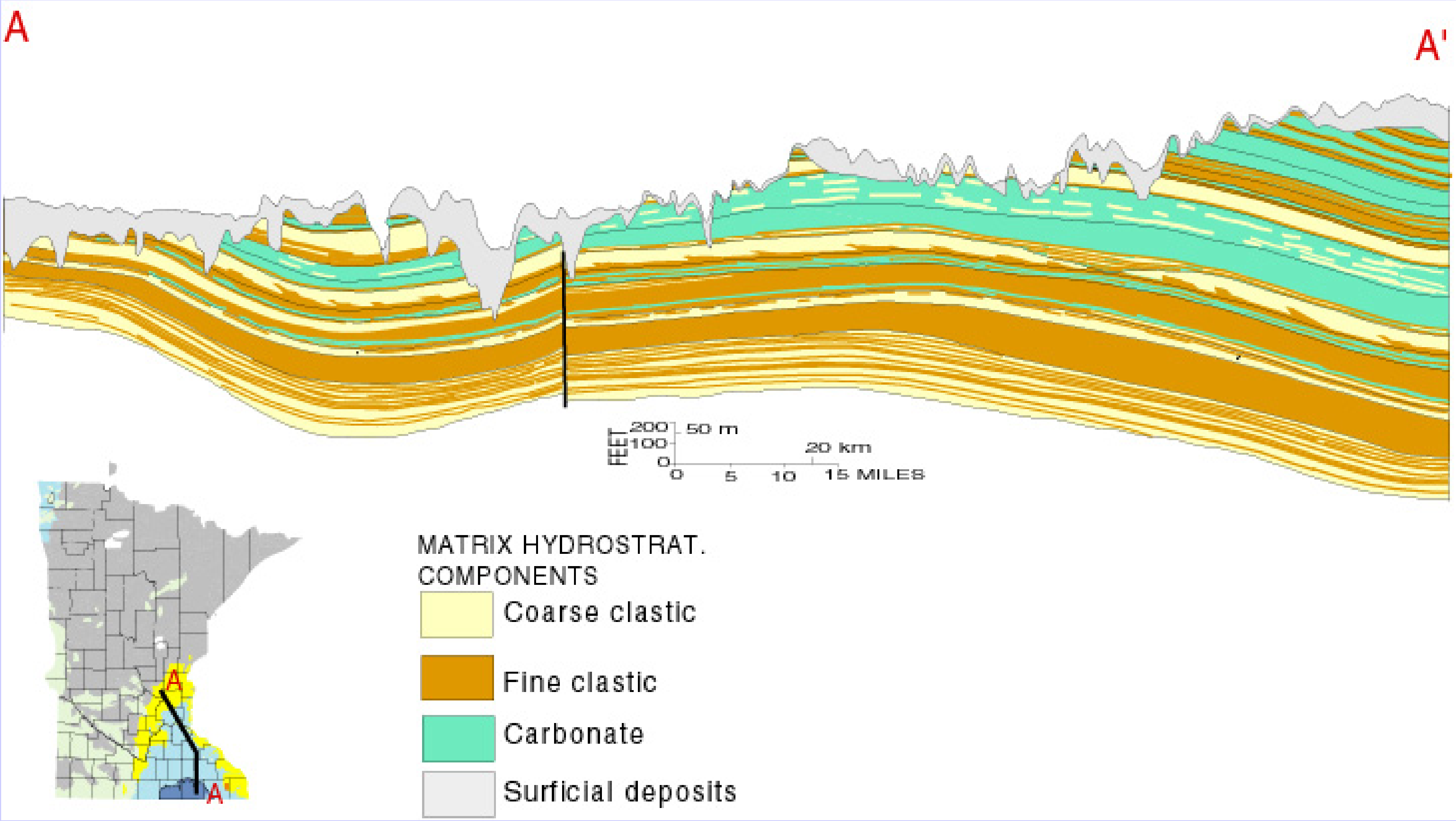
coarse clastic fine clastic carbonate



THOUSANDS OF PLUG SAMPLES TESTED FOR POROSITY, VERTICAL AND HORIZONTAL PERMEABILITY



Outcrops, natural gamma logs, borehole cuttings, cores and drillers logs used to map the three matrix components



SECONDARY PORES:
Outcrop observations

Dissolution cavities/bedding fractures preferentially developed along specific stratigraphic intervals

Plan view of what a “holey” interval might look like

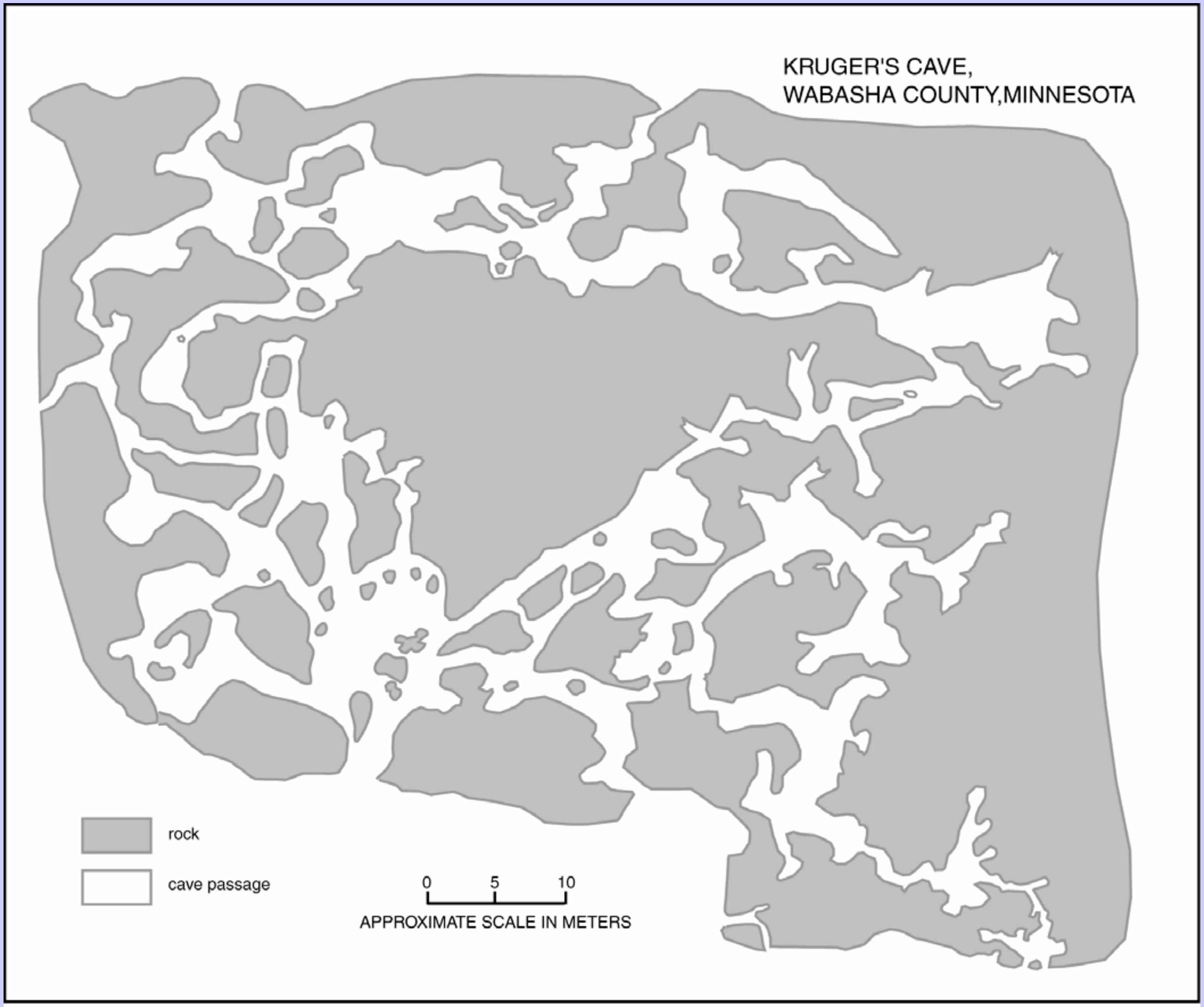
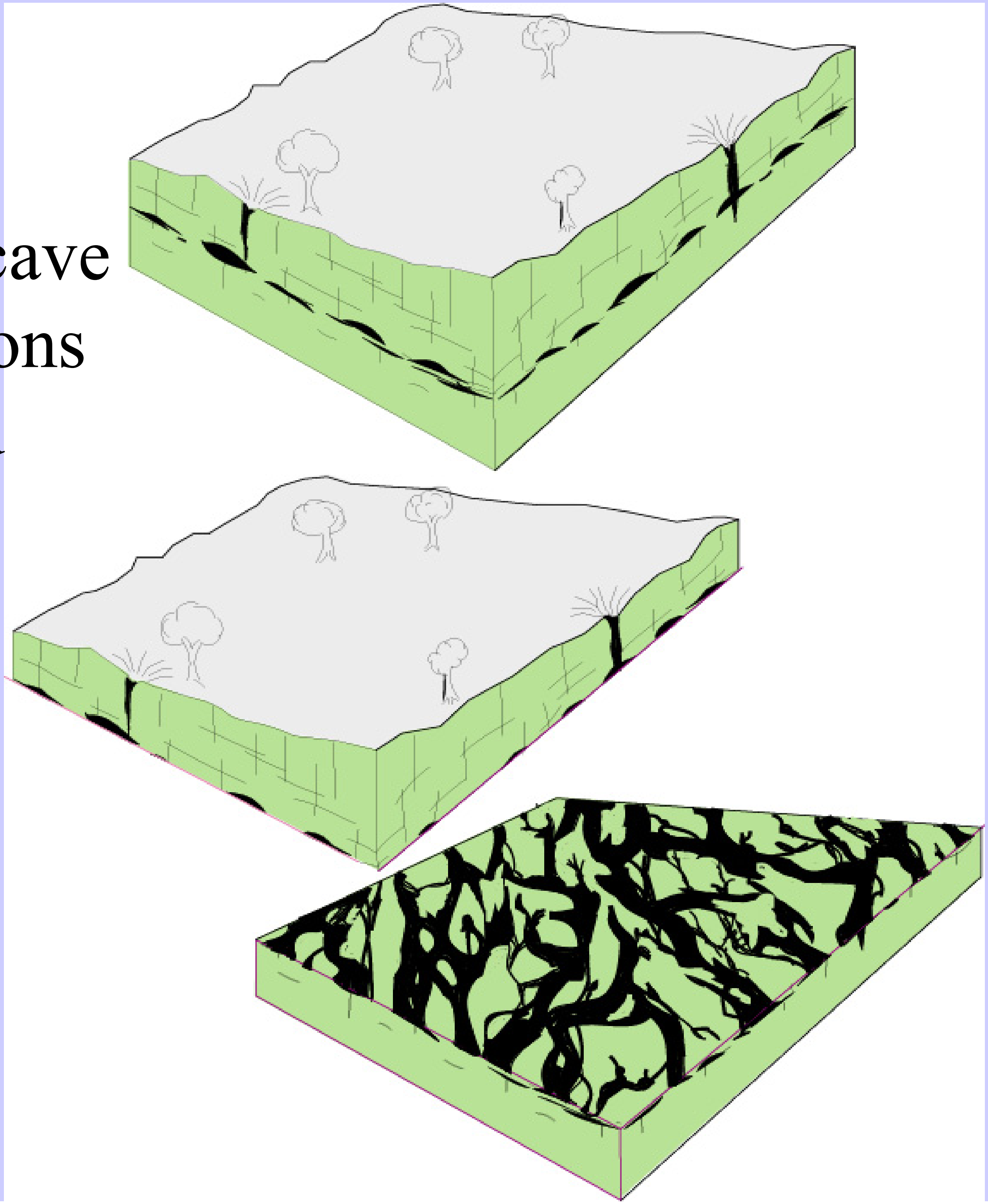


Figure 3

Outcrop/cave observations combined




Outcrop observations
Bedding plane fractures in sandstone and shale

Outcrop observations

Systematic fractures ("joints")

Outcrop observations

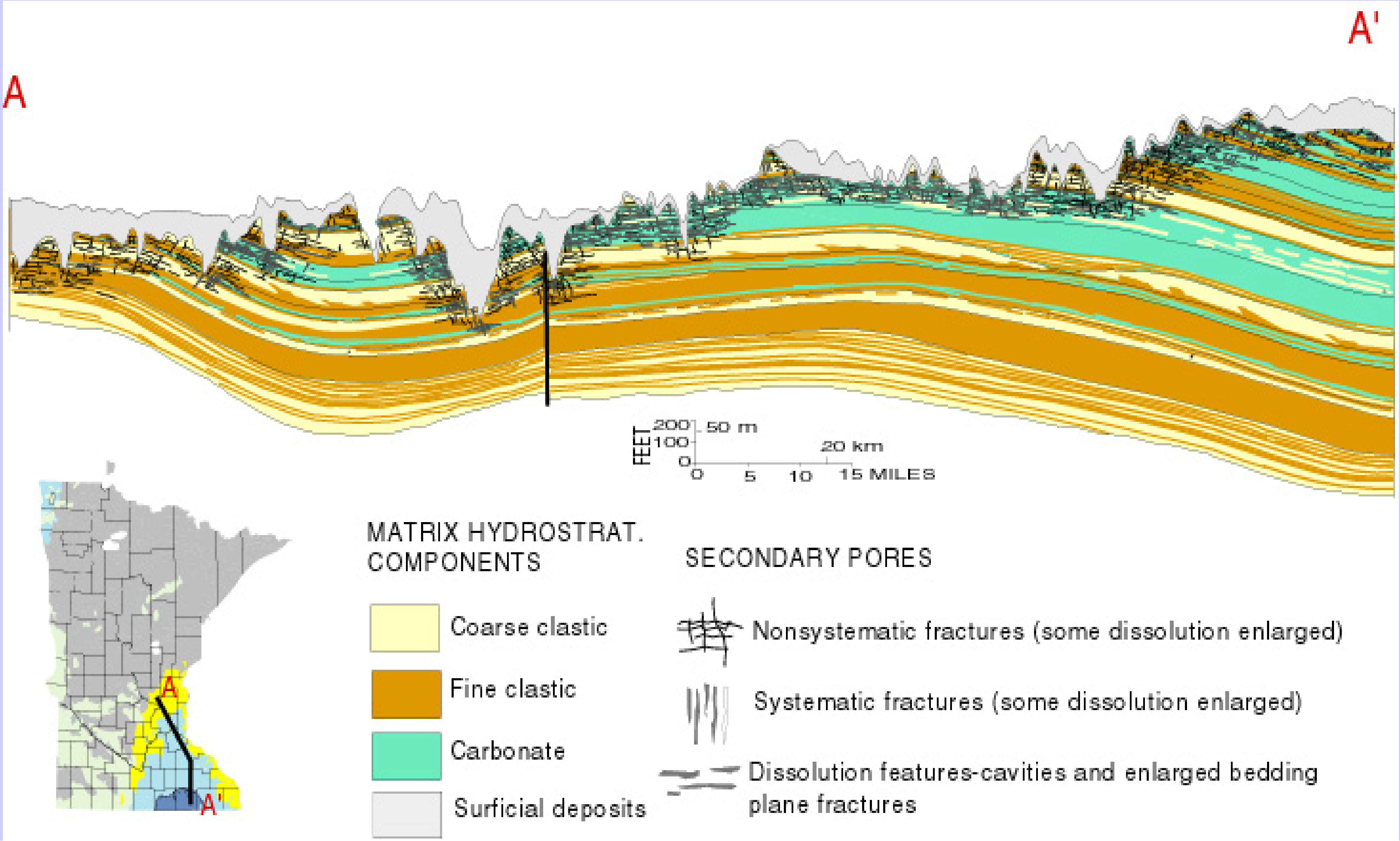
Nonsystematic (stress relief) fractures

Outcrop observations

Secondary pore abundance and aperture size diminishes with depth

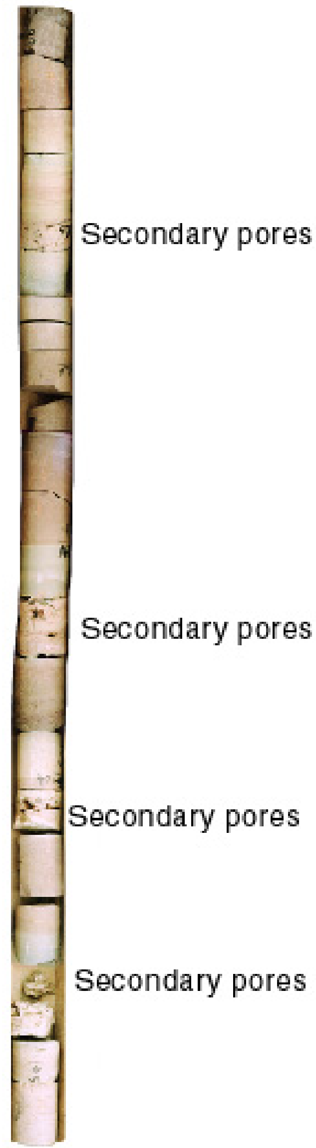
Secondary pores- Outcrop observations

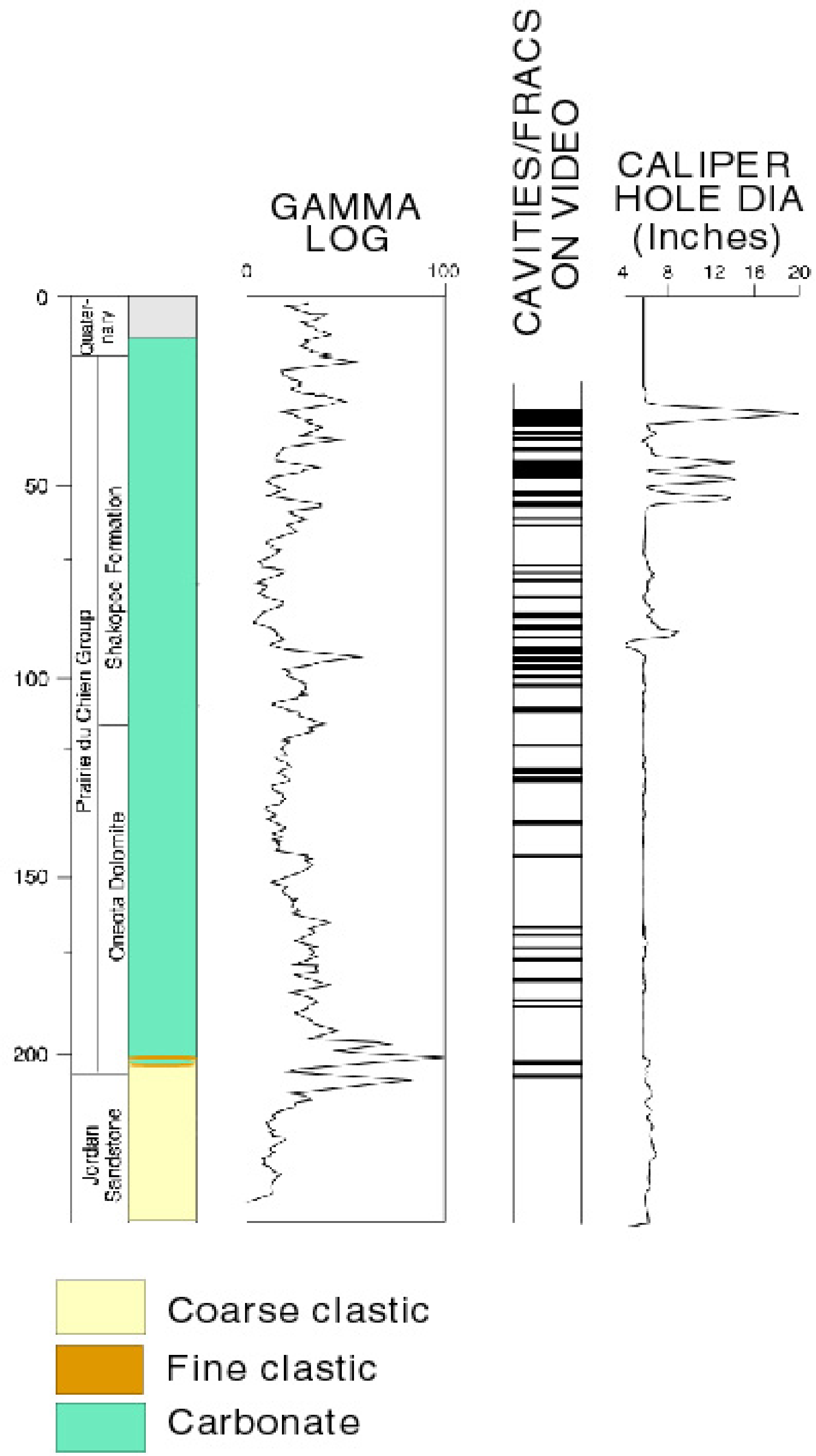
Outcrop, quarry, cave, tunnel observations combined



Deeper subsurface: Logging secondary pores in cores and boreholes

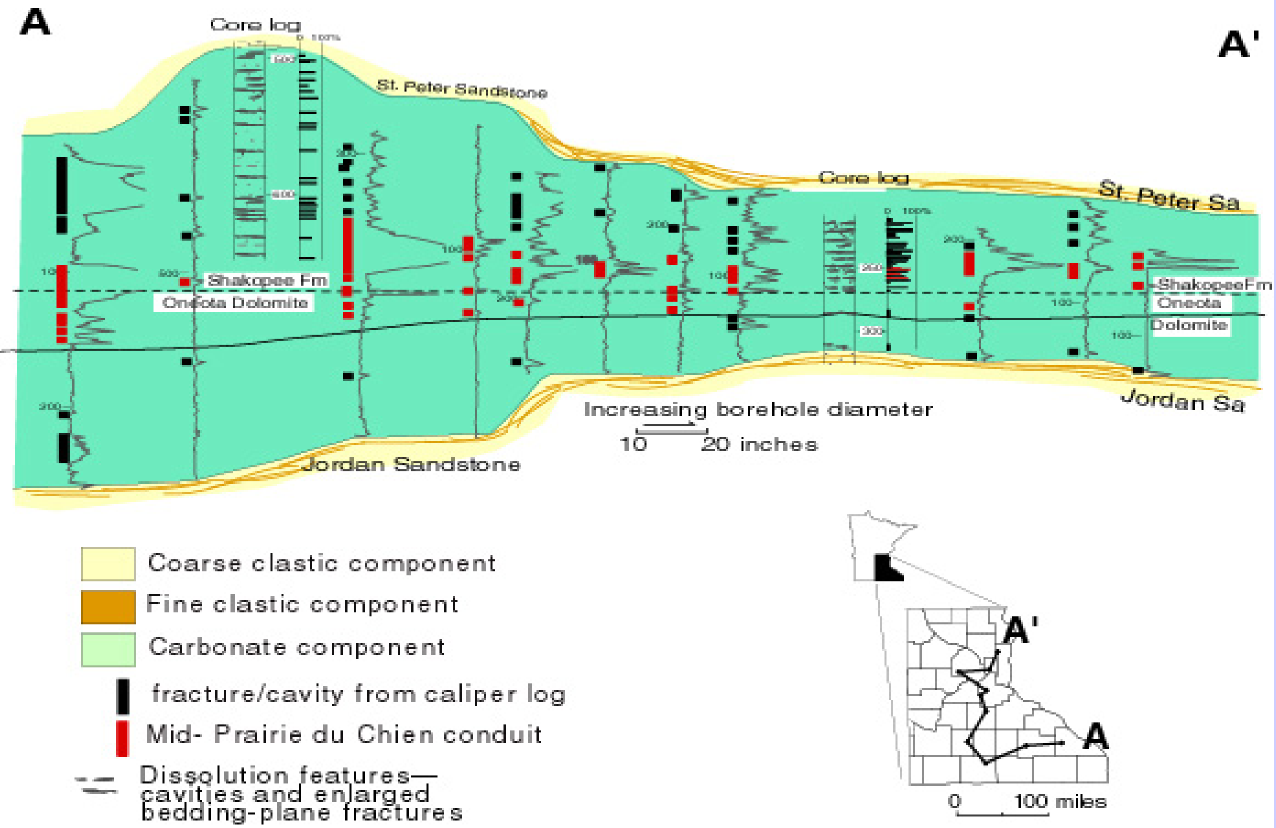
CORE LOGGING





Subsurface “mapping” of secondary pores indicates that stratigraphic intervals that are preferentially “holey” in outcrop are preferentially “holey” in deep (100’s ft) subsurface

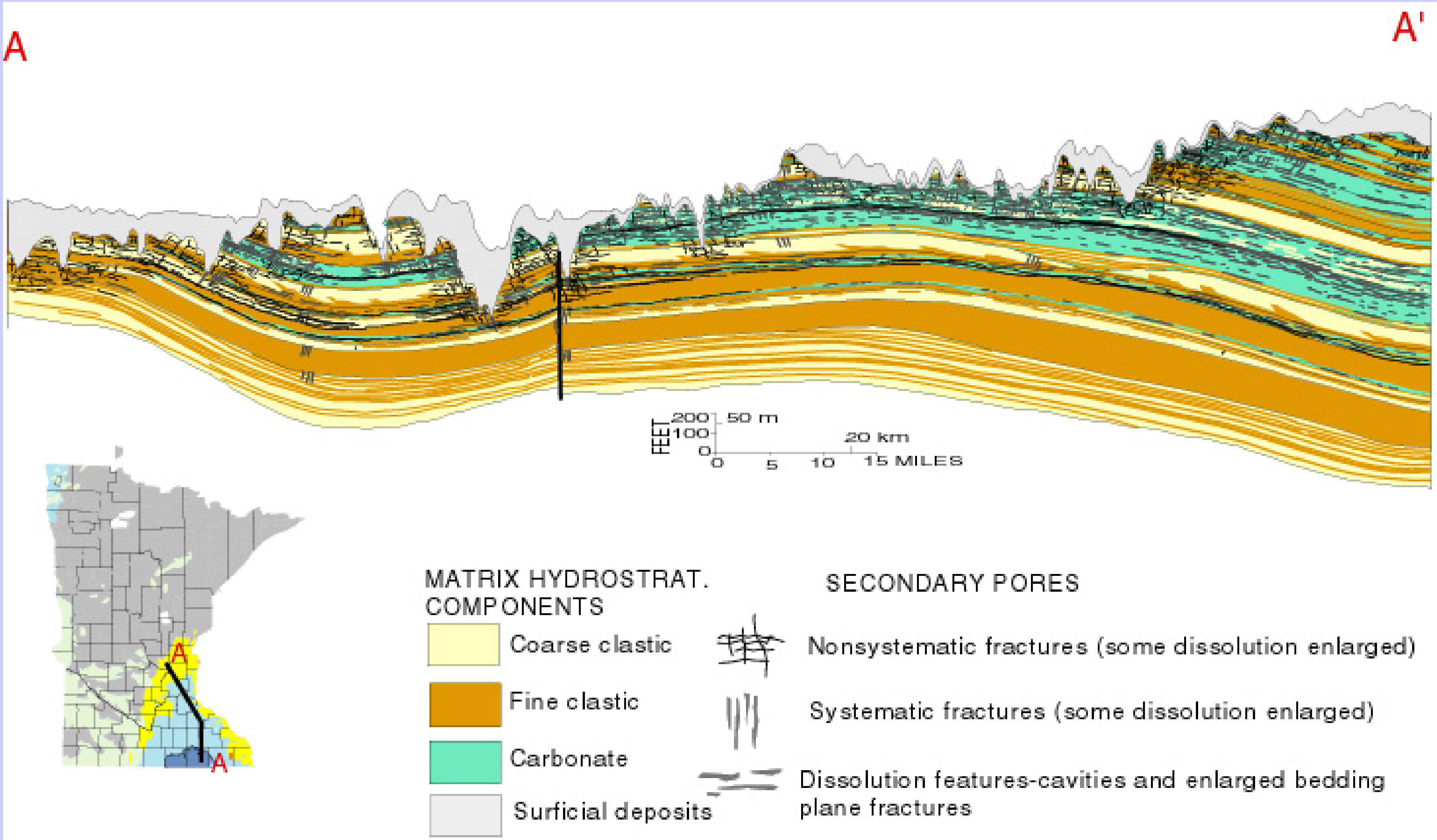
Similarly, stratigraphic intervals that have relatively few holes in outcrop are have few holes in deep subsurface



LOCATION OF CROSS-SECTION

Combined outcrop and subsurface information on matrix and secondary pores leads to a HYDROSTRATIGRAPHIC FRAMEWORK: I.e. a map of porosity

This is created independent of hydraulic data



Creating a hydrogeologic framework: collecting and interpreting "hydraulic" data within the context of the hydrostratigraphic framework

Key data:

Borehole flowmeter logs

Packer tests

Standard aquifer tests

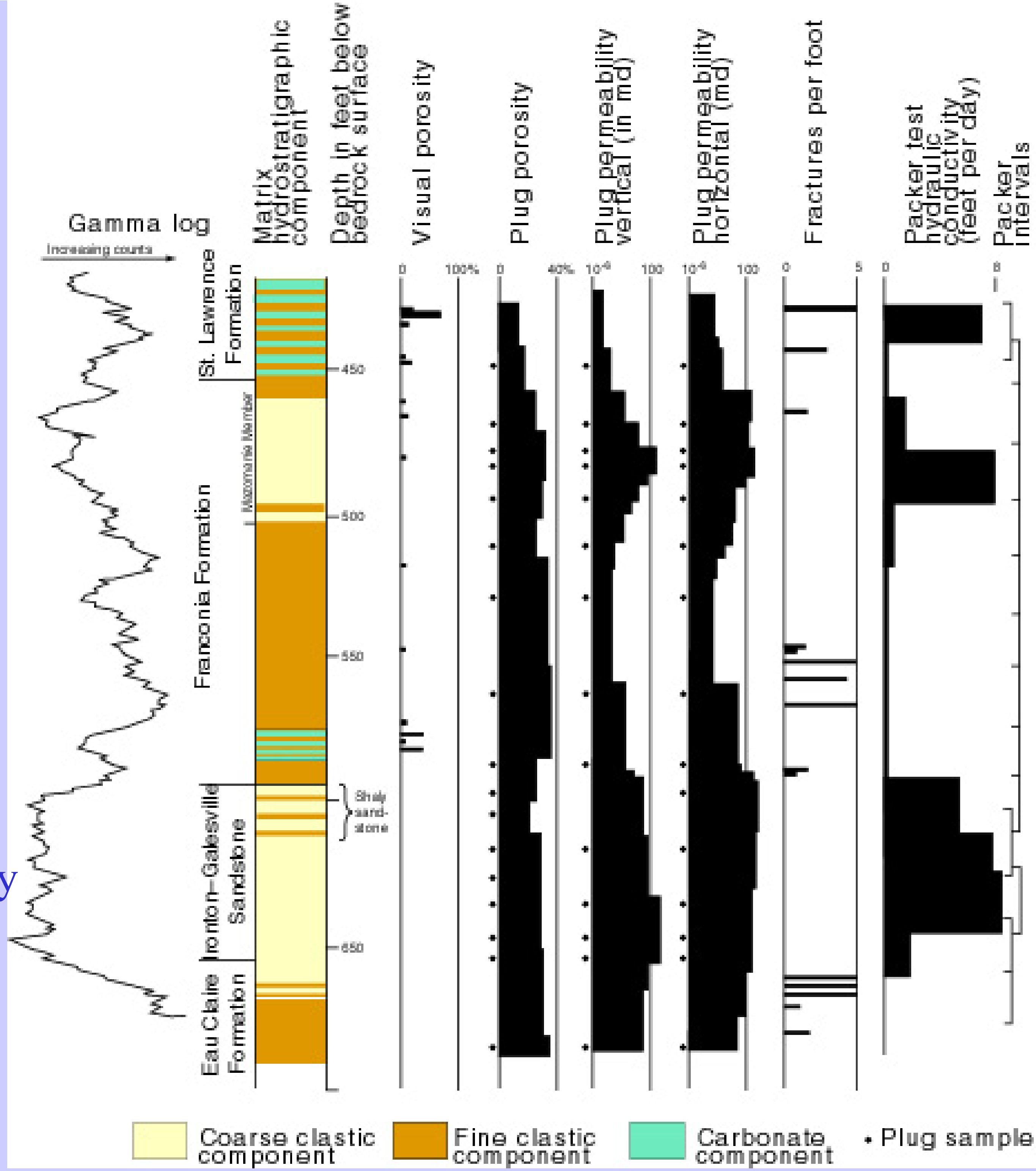
Specific capacity data (>8000)

Water chemistry (incl. dates)

Potentiometric data

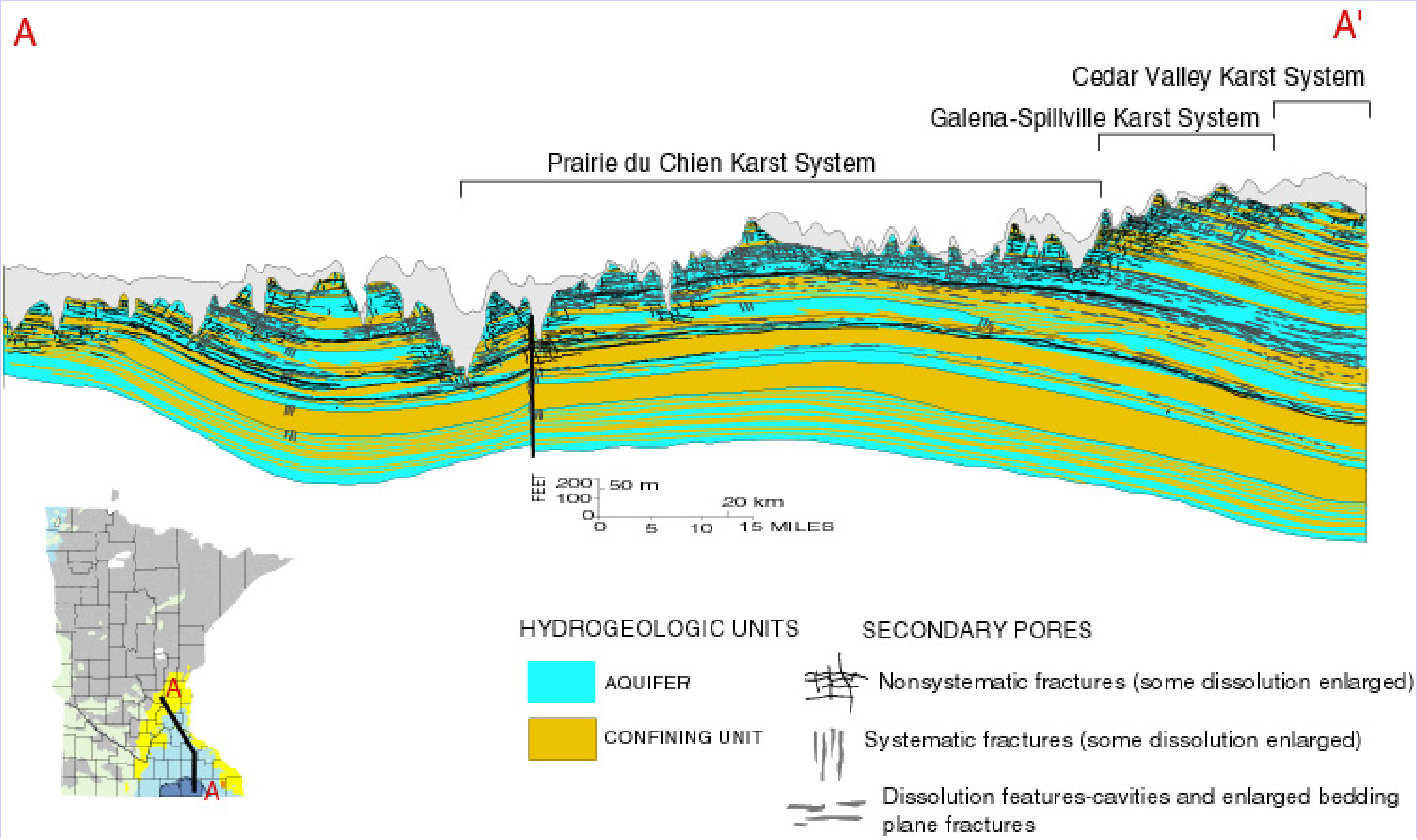
Stream loss/gain vs stratigraphy

Dye traces



Hydrostratigraphic and Hydraulic data combined

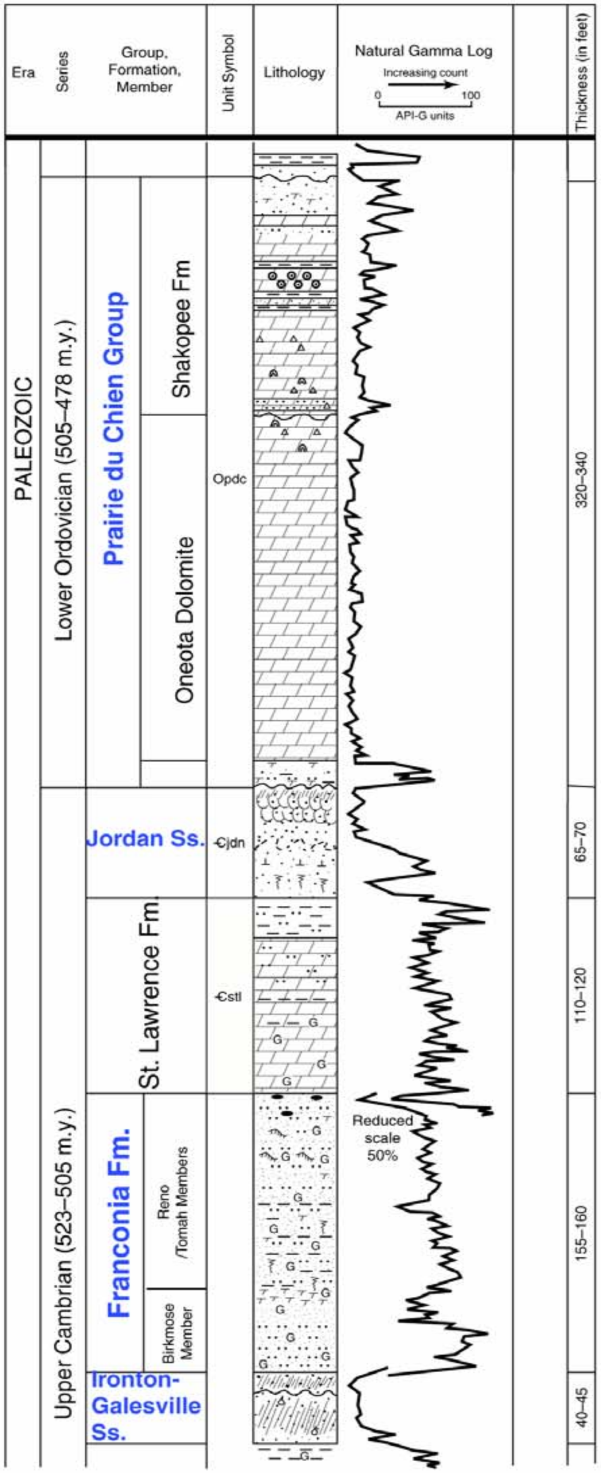
= HYDROGEOLOGIC FRAMEWORK

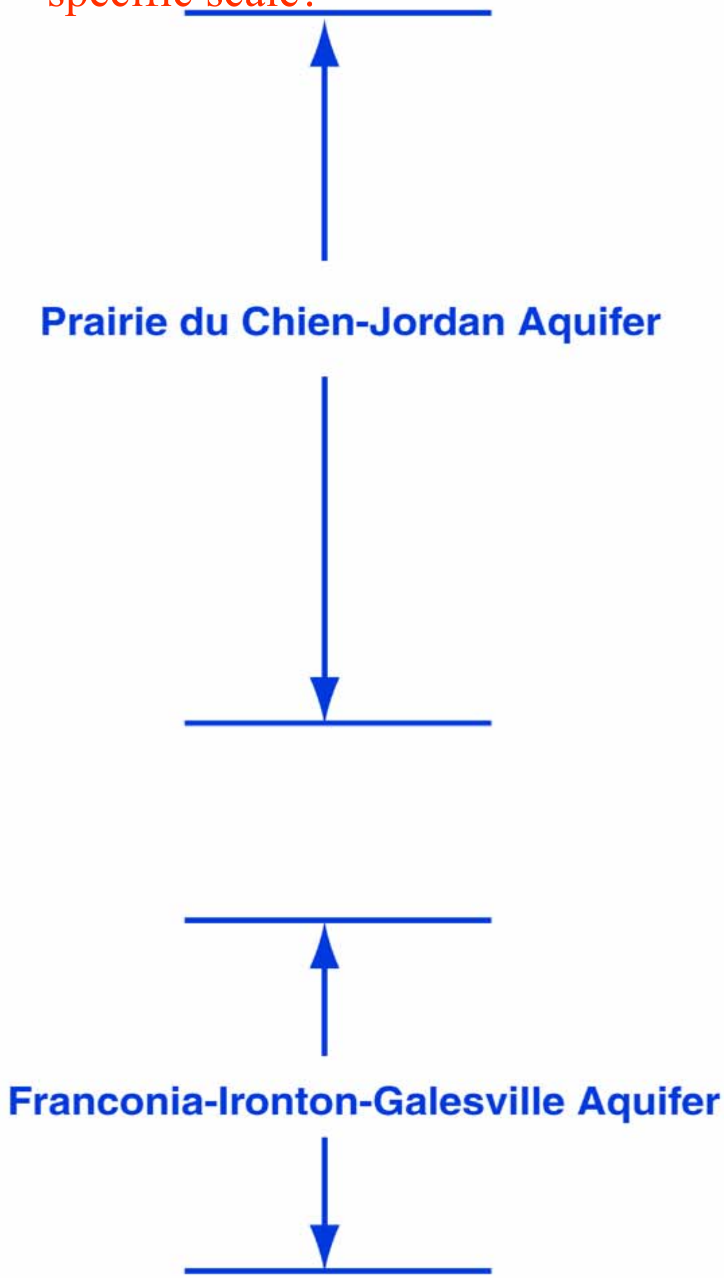


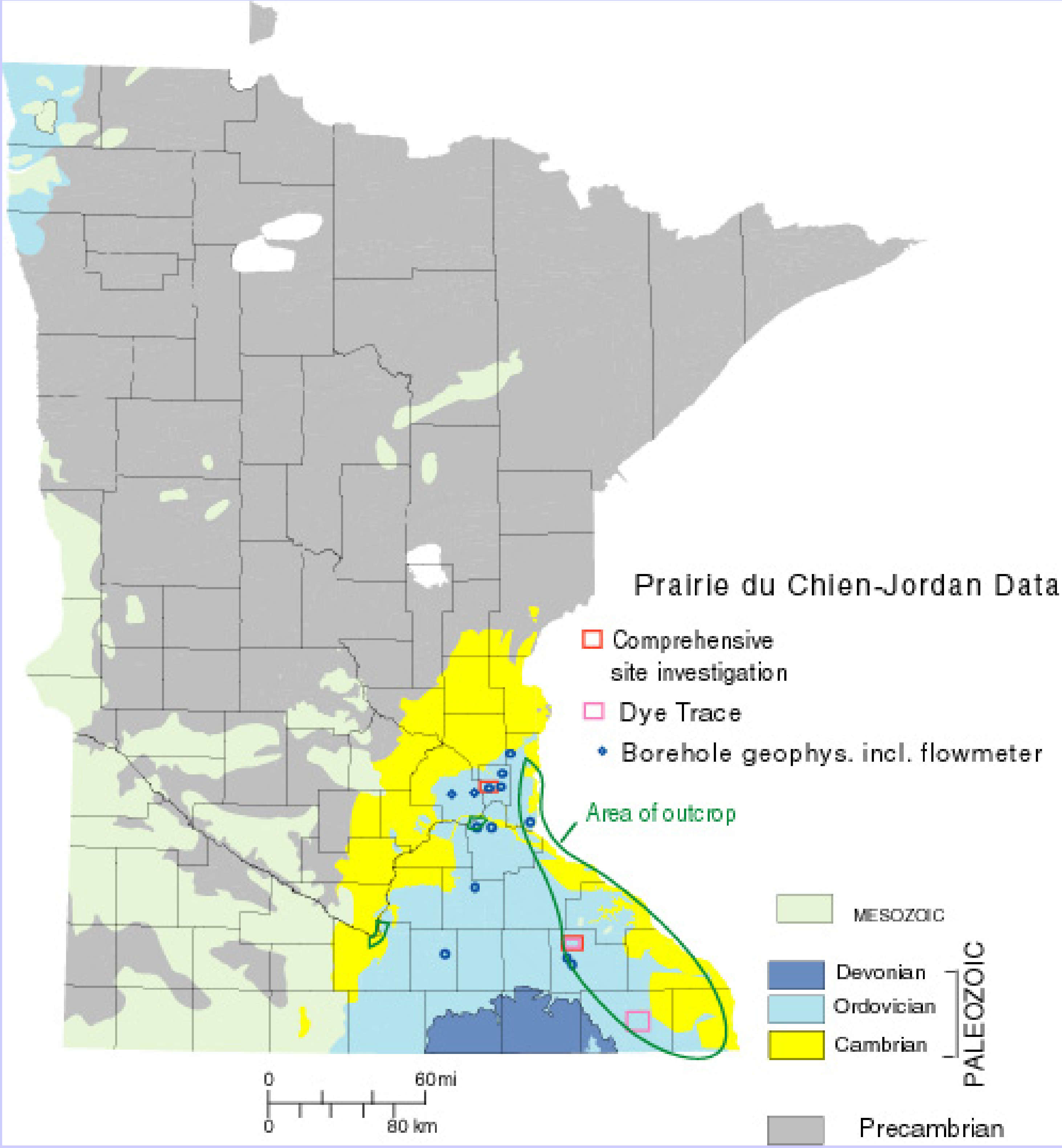
SPECIFIC EXAMPLES

Improvements provided by new framework

How does the system function at the site-specific scale?

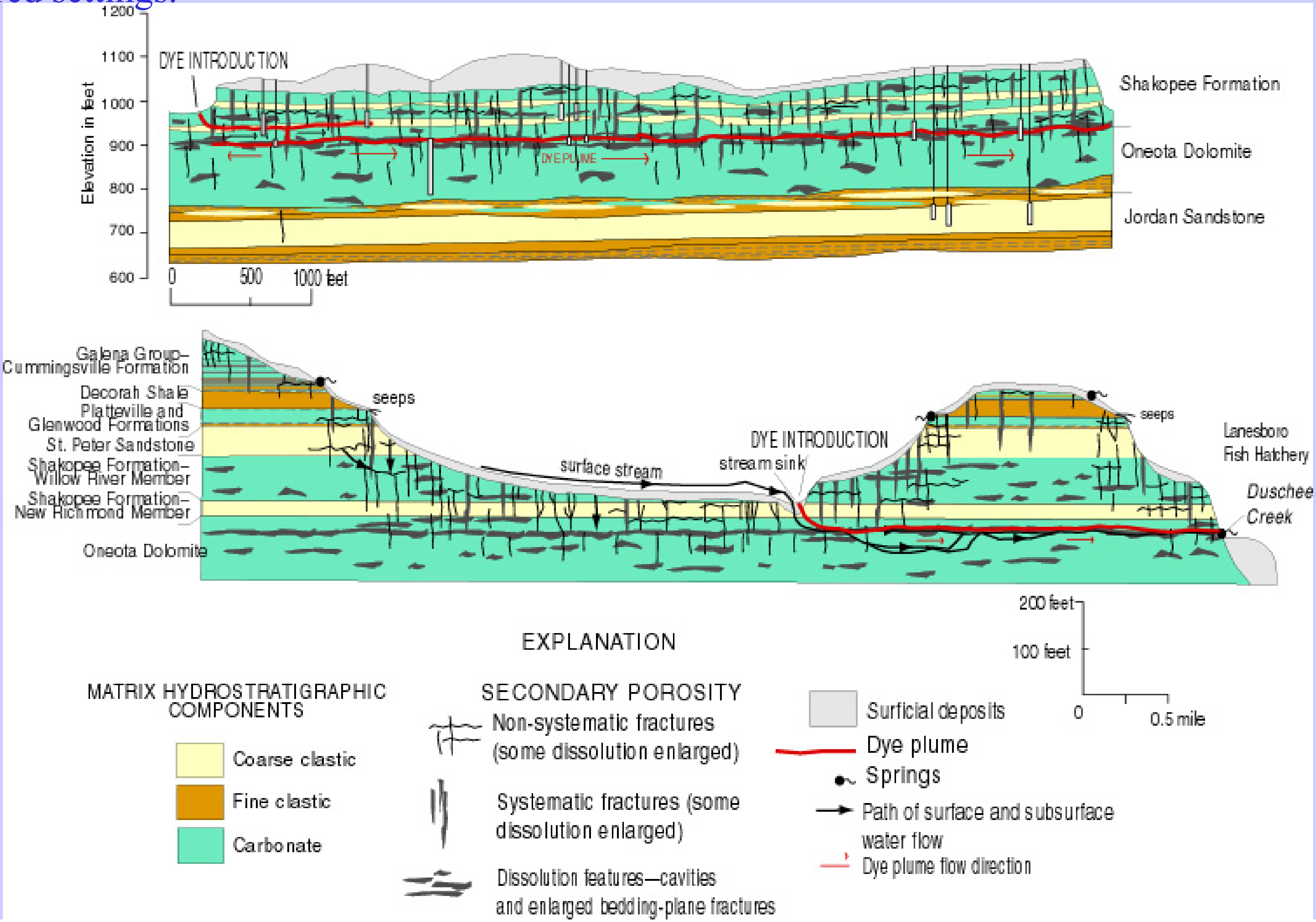




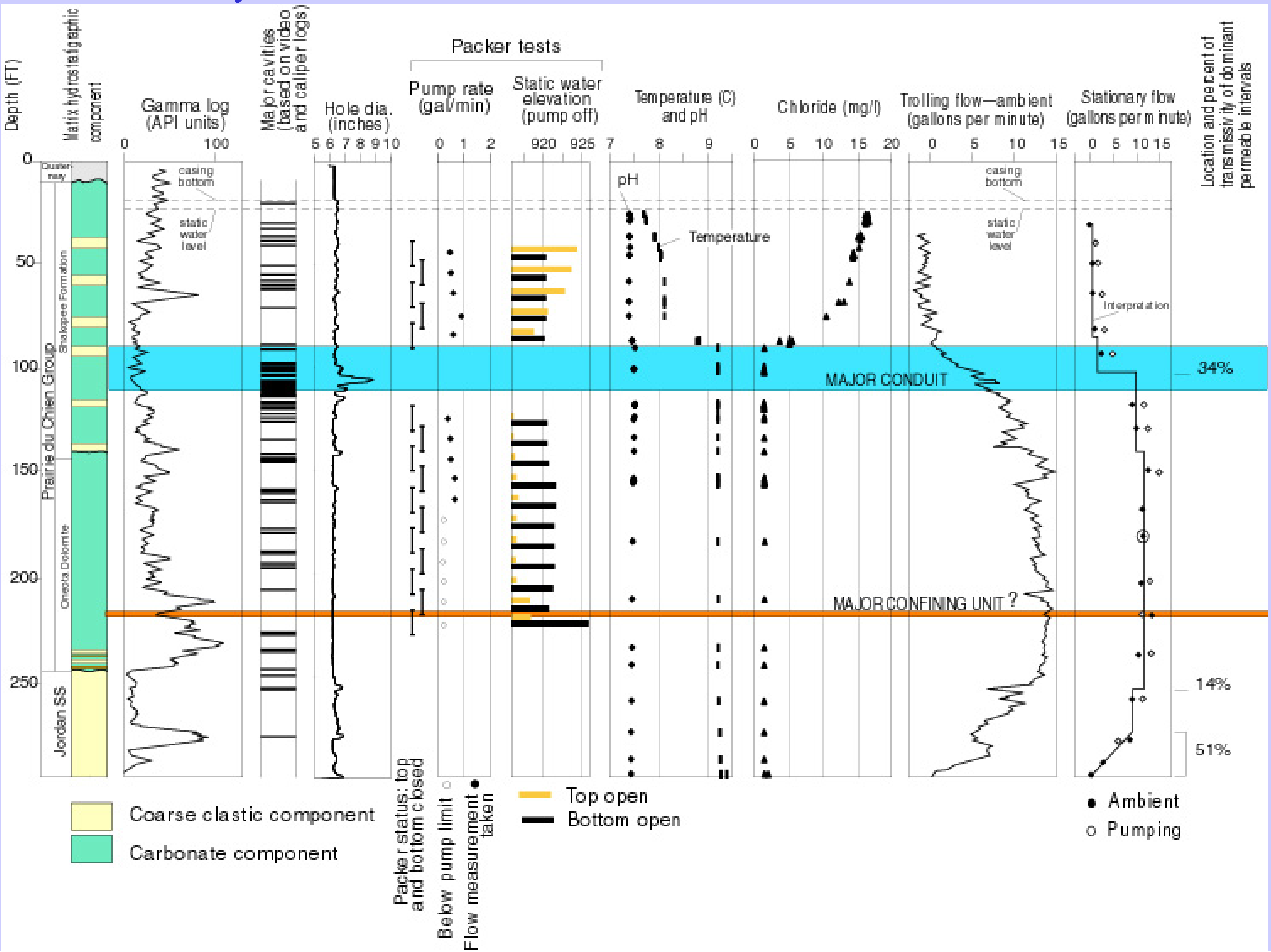

Prairie du Chien-Jordan Data
Comprehensive site investigation
Dye Trace
Borehole geophys. incl. flowmeter
Area of outcrop
MESOZOIC
Devonian
Ordovician
Cambrian
PALEOZOIC
Precambrian
0
60 mi
0
80 km

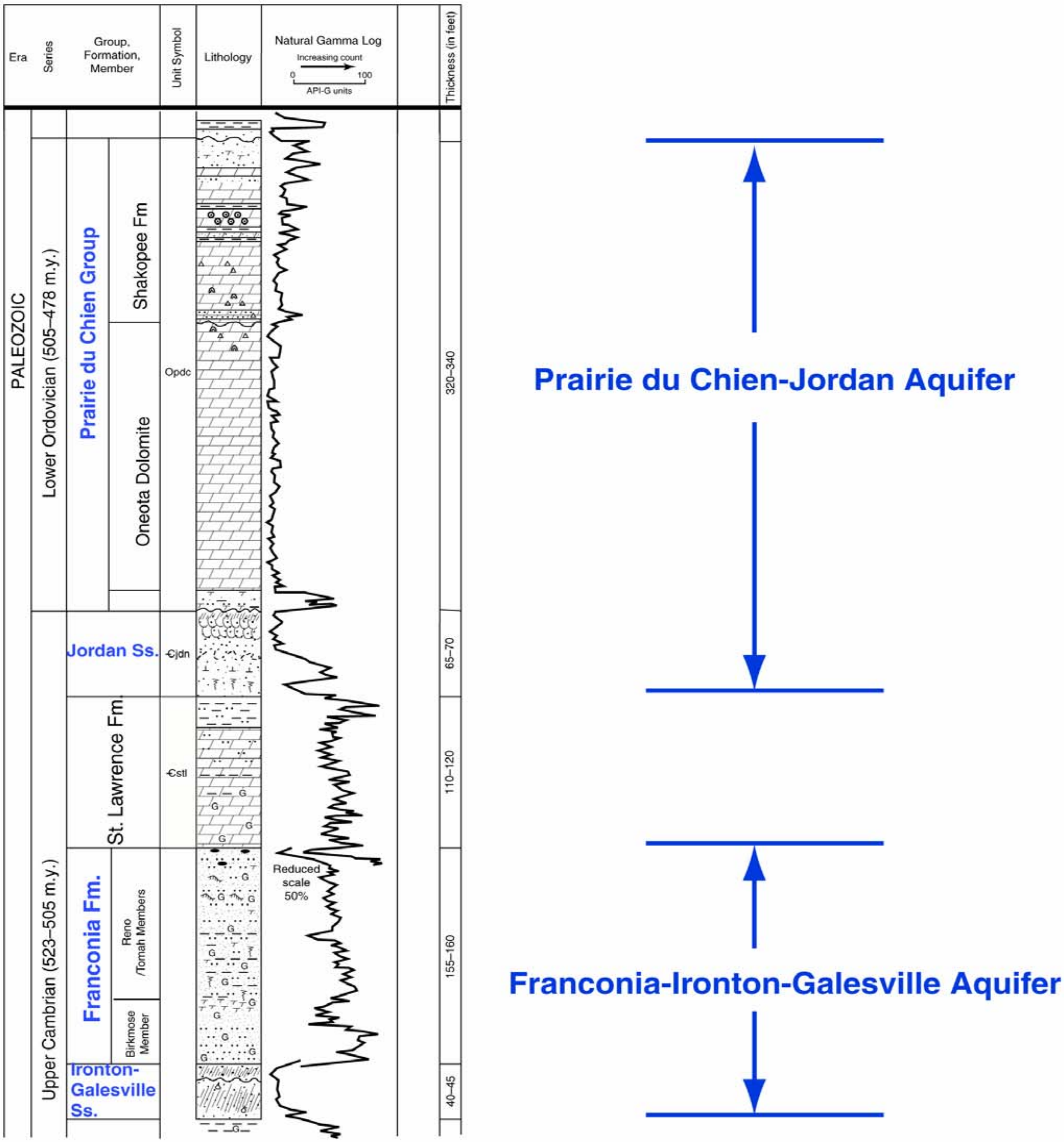
--Carbonate strata characterized by discrete stratigraphic intervals with exceptionally high conductivity that dominate the system.

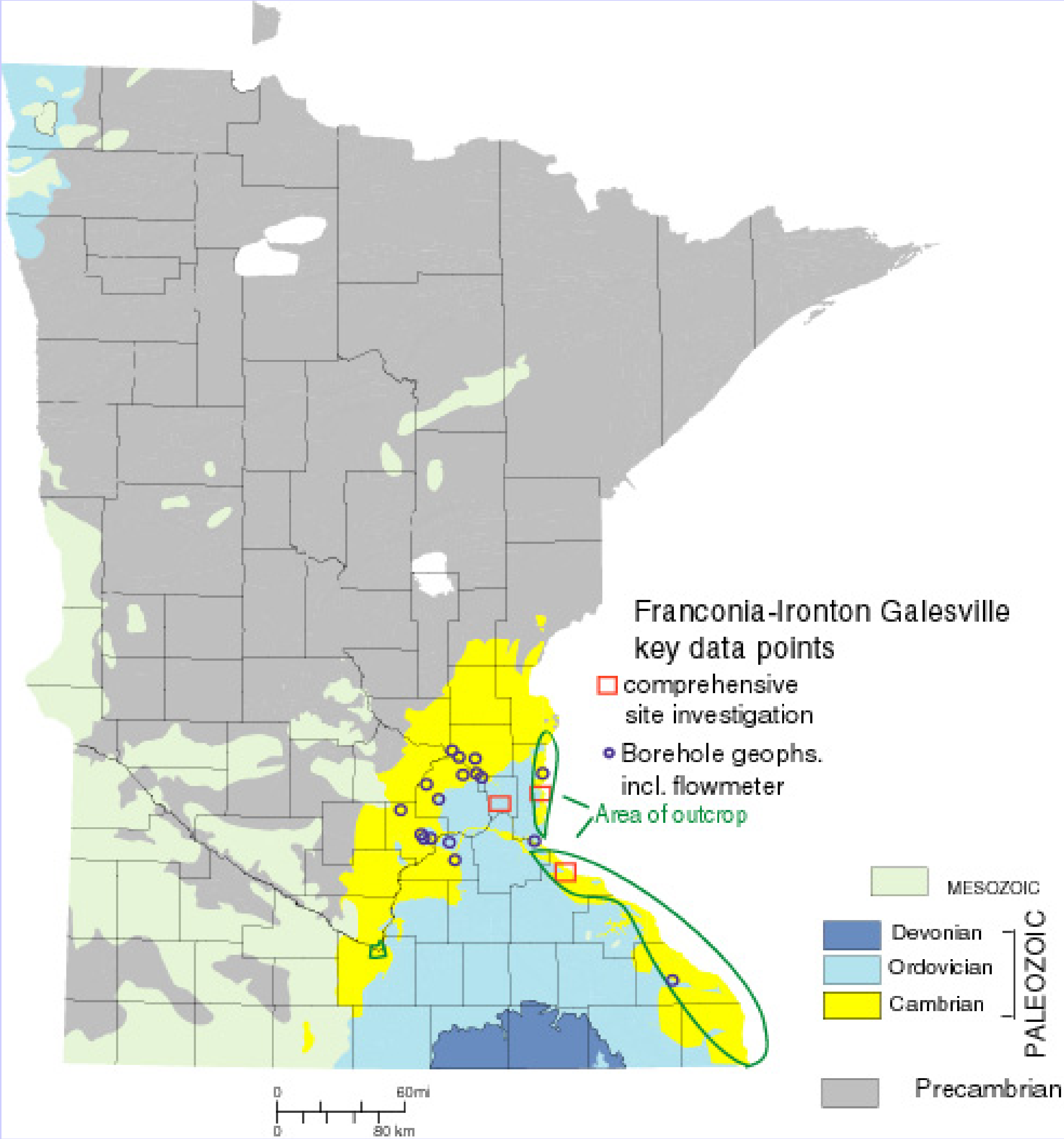
--Similarly, discrete stratigraphic intervals appear to serve as barriers, even in near-surface fractured settings.



Typical character of an individual borehole: Discrete stratigraphic intervals provide confinement, and dominate well hydraulics

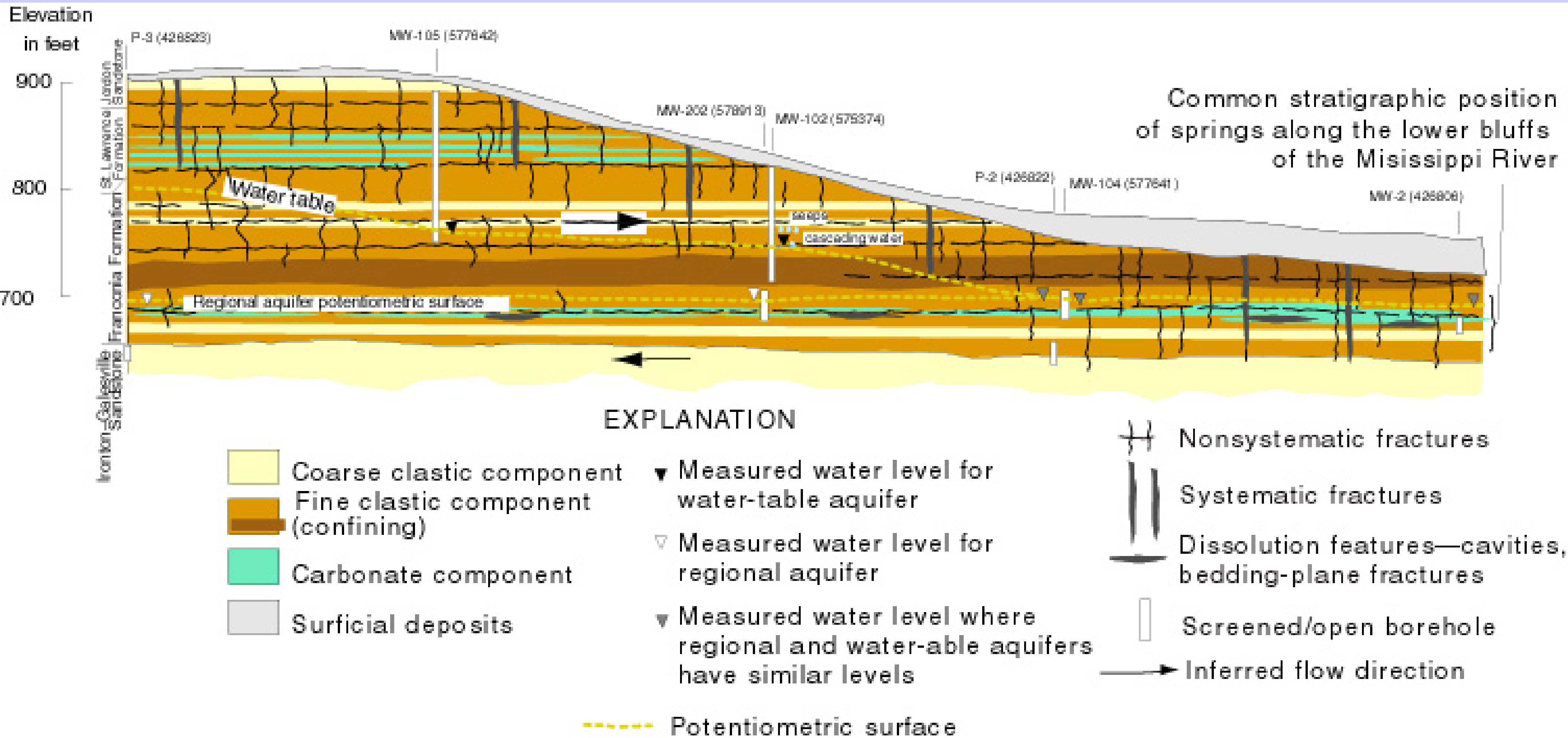



Era
Series
Group, Formation, Member
Unit Symbol
Lithology
Natural Gamma Log
Increasing count
0
100
API-G units
Thickness (in feet)
PALEOZOIC
Lower Ordovician (505–478 m.y.)
Prairie du Chien Group
Shakopee Fm
Oneota Dolomite
Opdc
320–340
Upper Cambrian (523–505 m.y.)
Jordan Ss.
€jdn
65–70
St. Lawrence Fm.
€stl
110–120
Franconia Fm.
Reno /Tomah Members
Birkmose Member
Reduced scale 50%
155–160
Ironton-Galesville Ss.
40–45
Prairie du Chien-Jordan Aquifer
Franconia-Ironton-Galesville Aquifer

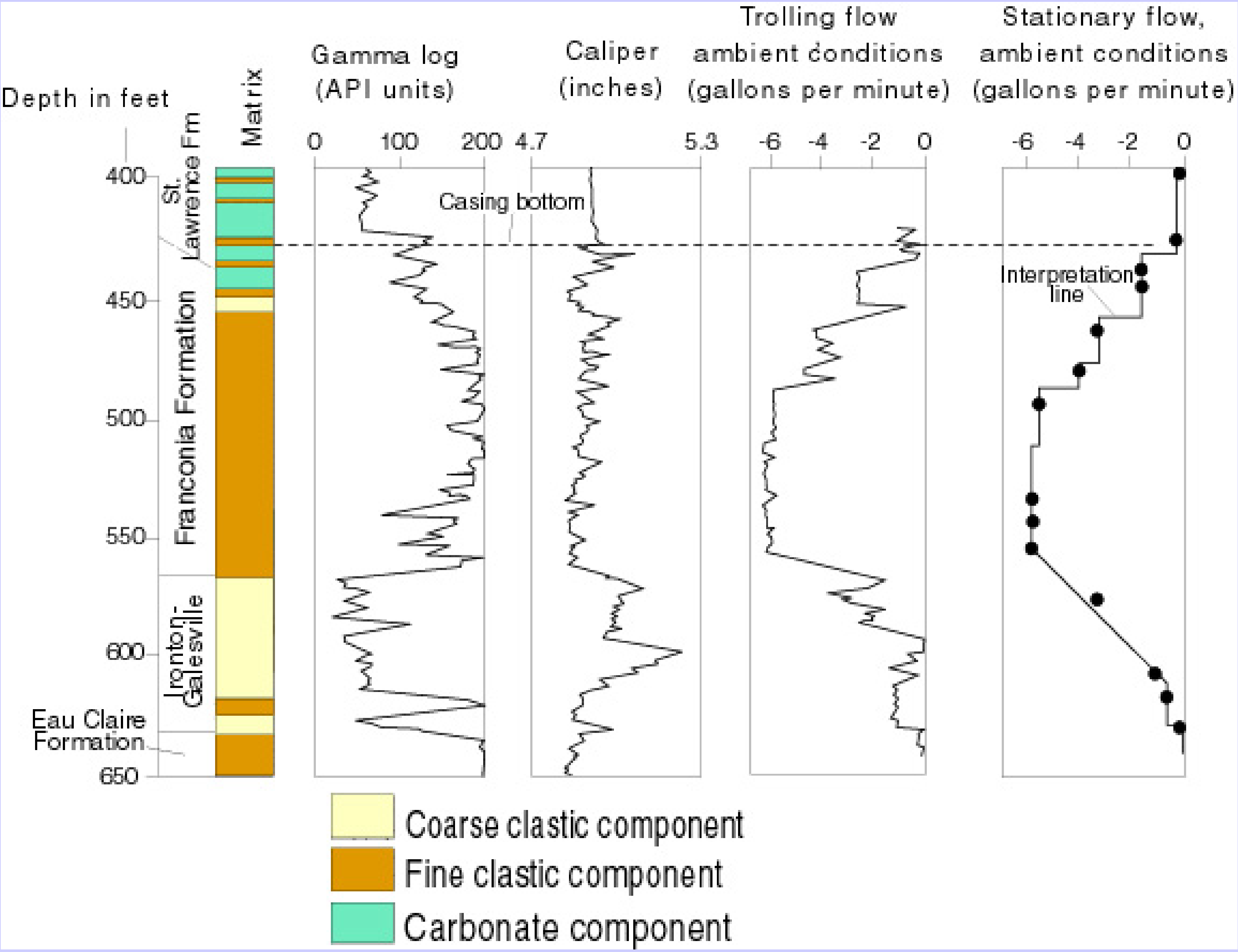

Franconia-Ironton Galesville
key data points
comprehensive
site investigation
Borehole geophs.
incl. flowmeter
Area of outcrop
MESOZOIC
Devonian
Ordovician
Cambrian
PALEOZOIC
Precambrian
0
60mi
0
80 km

Siliciclastic strata appear to function much like the carbonate strata

Rapid, high volume flow through secondary pores
Discrete stratigraphic intervals are conduits or barriers

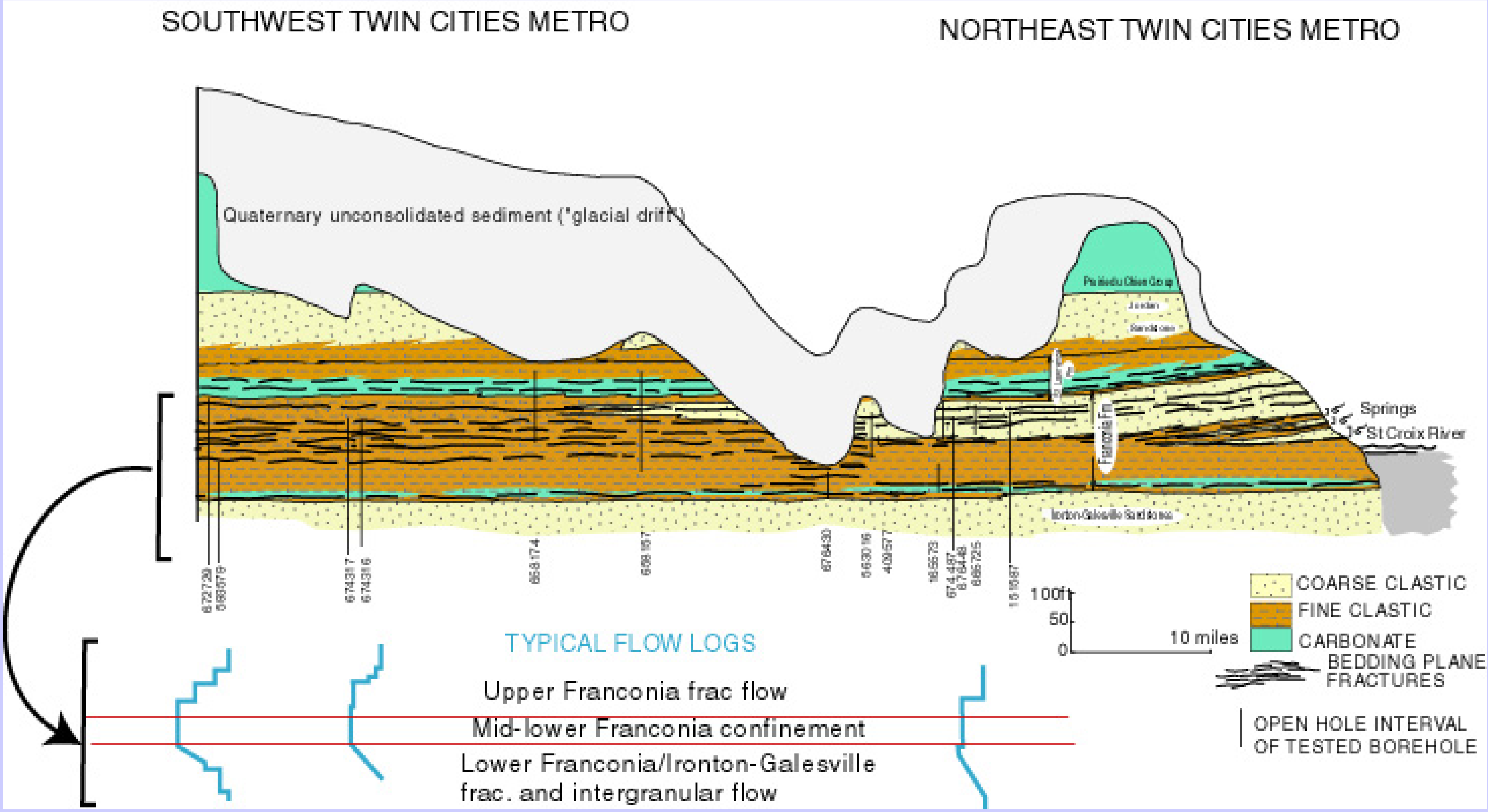


TYPICAL FLOW LOG OF SILICICLASTIC STRATA



Correlated flowmeter logs demonstrate:

1) bedding plane fractures dominate even in sandstone with high porosity
2) bedding plane fractures preferentially occur in specific stratigraphic interval
3) specific stratigraphic interval apparently largely unbreached by frac.s and acts as barrier



Another example
of outcrops providing
insight into “deep”
subsurface conditions

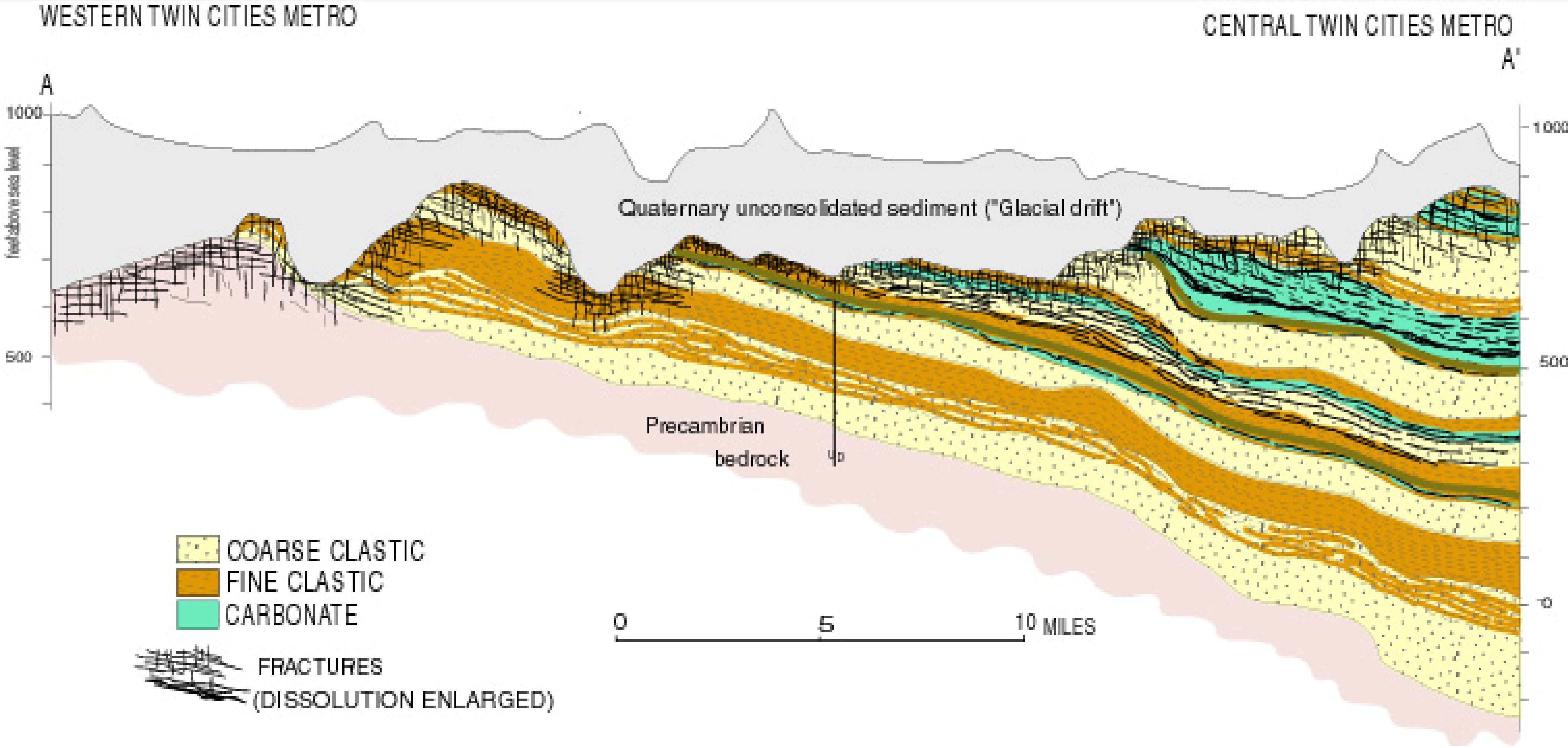
SUMMARY:

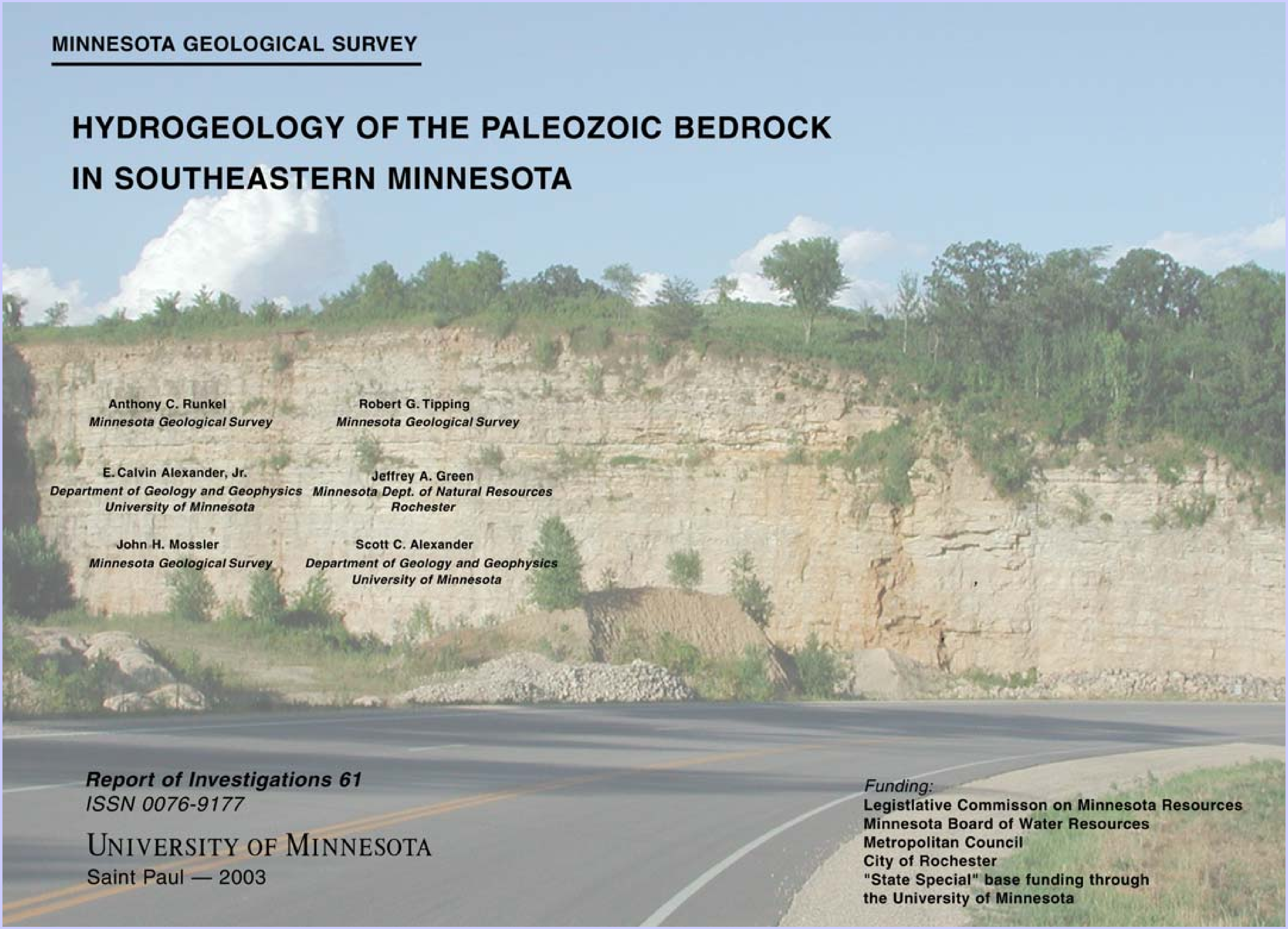
--A rigorous construction of a regional-scale hydrostratigraphic and hydrogeologic framework can provide useful information even for site specific scale investigations

--All bedrock has secondary pores

--Even in the relatively tectonically stable craton, and in some of the most porous, friable sandstone bedrock known, secondary pores are important groundwater conduits

--Secondary pore development is predictable to some degree, because to some degree it is stratigraphically controlled.





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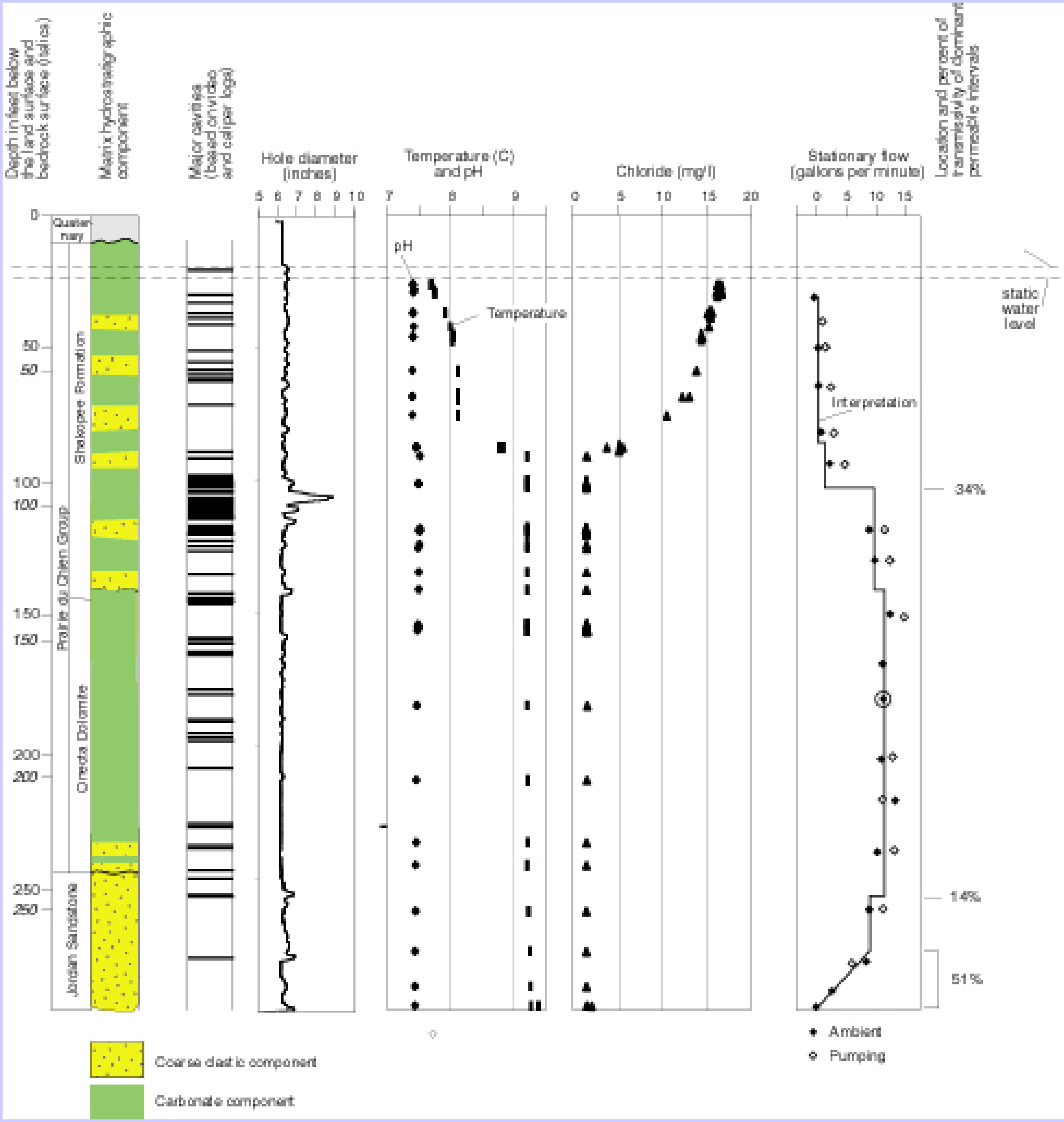
Depth in feet below the land surface and bedrock surface (italics)
Matrix hydrostratigraphic component
Major cavities (based on video and caliper logs)
Hole diameter (inches)
Temperature (C) and pH
Chloride (mg/l)
Stationary flow (gallons per minute)
Location and percent of transmissivity of dominant permeable intervals
Quaternary
Shakopee Formation
Prairie du Chien Group
Oneota Dolomite
Jordan Sandstone
pH
Temperature
Interpretation
static water level
34%
14%
51%
Ambient
Pumping
Coarse clastic component
Carbonate component